Laws and Principles of Concrete Mixture Design

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How I grew up…

Concrete Mix Design

What are these numbers?!

The Batch Ticket

READY- MIX CONCRETE COMPANY NAME
STREET NUMBER
CITY, STATE ZIP CODE

PURCHASER:

PROJECT ADDRESS:

DATE:	PLANT NO:	TRUCK NO:	TICKET NO:

MIXTURE ID:

DESCRIPTION/DESIGNATION
OF MIXTURE DESIGN:

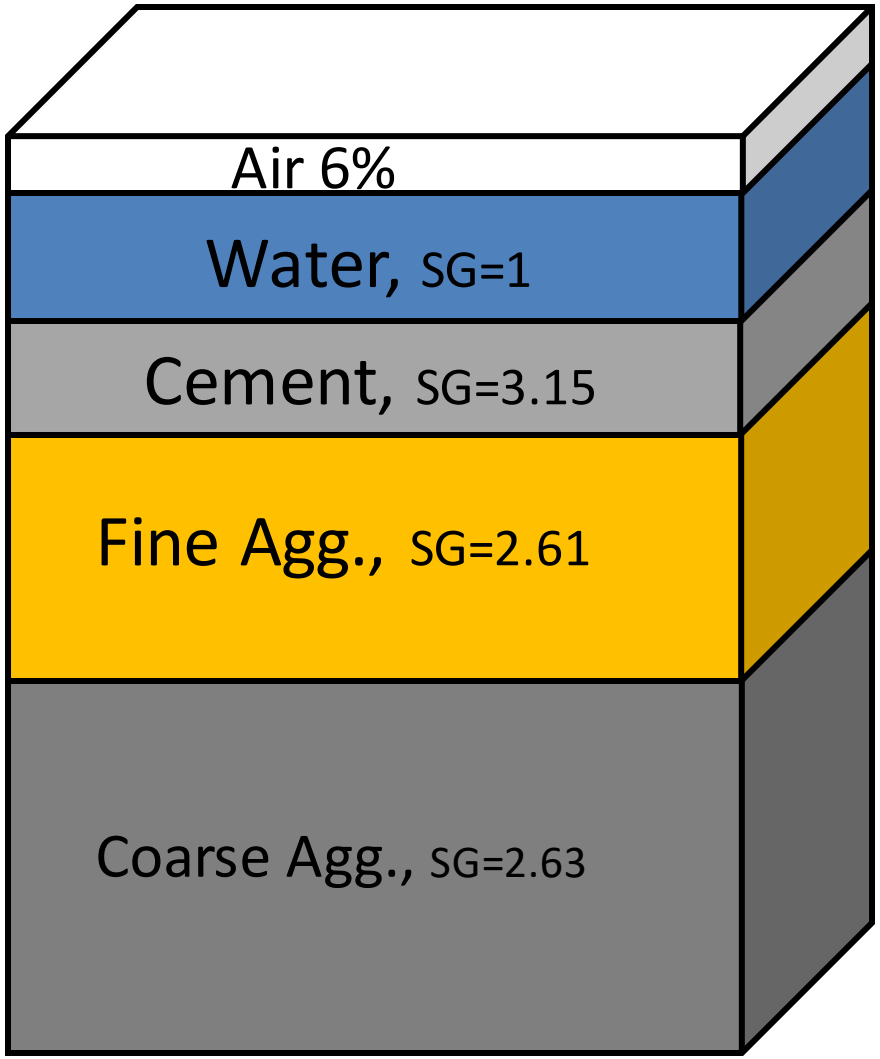
MATERIAL	SOURCE INFORMATION	DESIGN WEIGHT	BATCHED WEIGHT
CEMENT			
FLY ASH			
WATER			
COARSE			
FINE			
ADMIXTURE			

LOAD TIME:
DELIVERY TIME:
REVOLUTIONS OF DRUM:
WATER ADDED:

VOLUME:

ACCEPTED BY: _____

Design Wt. (lbs.)	**Material**	**Volume** (ft^3)
---	Air 6%	1.62 ft^3
250 lbs.	Water, SG=1	4.01 ft^3
564 lbs.	Cement, SG=3.15	2.87 ft^3
1226 lbs.	Fine Agg., SG=2.61	7.53 ft^3
1800 lbs.	Coarse Agg., SG=2.63	10.97ft^3
		27.00 ft^3



Weight & Volume of Concrete

Sold by Volume (per yd^3)

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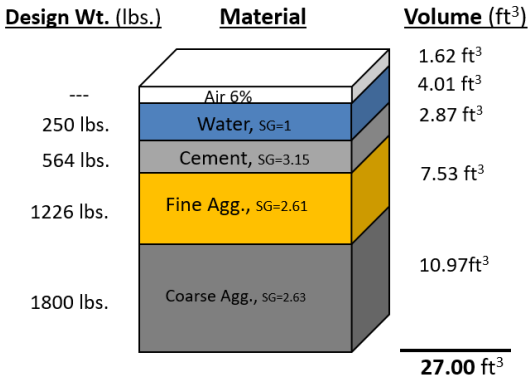
Example



Designed by Volume (1 yd^3)

Batched by Wt. (lbs.) & Vol (oz. or gals)

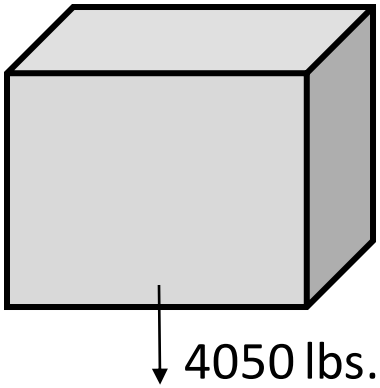
Design & Batching

Material	Designing Concrete		Batching Concrete	
	Design	Units	Batch	Units
Cement	Weight	lbs.	Weight	lbs.
Fly ash	Weight	lbs.	Weight	lbs.
Slag	Weight	lbs.	Weight	lbs.
Silica Fume	Weight	lbs.	Weight	lbs.
Stone	Both	lbs., ft^3	Weight	lbs.
Sand	Both	lbs., ft^3	Weight	lbs.
Water	Both	lbs., gal	Volume	gals
Liquid Admix	Volume	oz/cwt	Volume	oz/yd^3
Powdered Admix	Volume	ft^3	Weight	lbs.
Air	Volume	ft^3	Volume	$oz./yd^3$

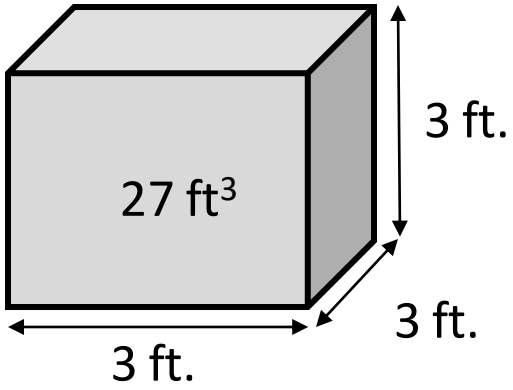
Weight, Volume, Density

- All matter has weight and occupies space

Weight (lbs.)

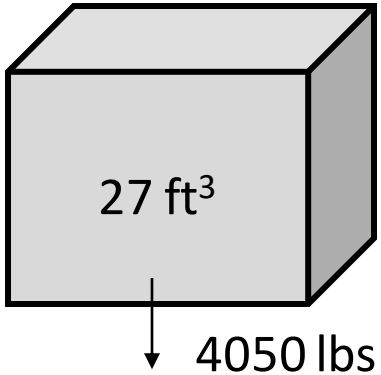


Volume (ft^3)



Volume= 3ft x 3ft x3ft =$27ft^3$

Density ($lbs./ft^3$)



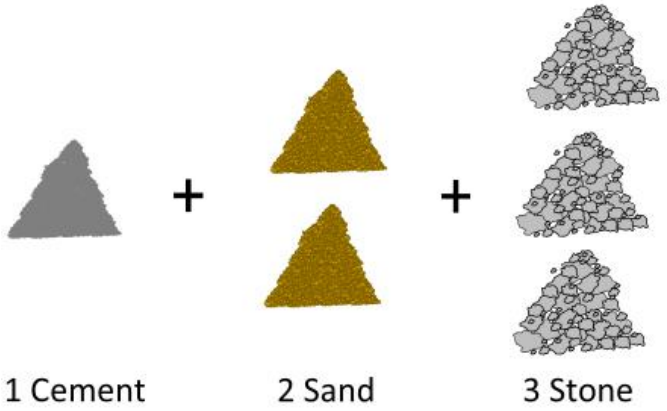
Density of water is 62.4 $lbs./ft^3$

$$\text{Density} = \frac{4050 \text{ lbs.}}{27 \text{ ft}^3} = 150 \text{ lbs./ft}^3$$

Roughly the density of normal concrete

Mix Design Methods

- **ACI 211** (absolute volume):
- **Trial batch method** (iterate):
- **Volume/weight estimate method**:
- **Aggregate design methods:**
  - Tarantula Curve, Shilstone CF Chart, packing



1-2-3 Method

The *TARANTULA* curve!

Fine sand
sum of #30
through #200
Between 24 to 34%
for slip formed
Between 25 to 40%
for flowable

Coarse sand
sum of #8
through #30
greater
than 20%

Increases cohesion

Decreases workability and promotes segregation

Decreases workability

Not in Scope of work

Creates surface finishing problems

% Retained

35%
30%
25%
20%
15%
10%
5%
0%

#200 #100 #50 #30 #16 #8 #4 0.375 0.5 0.75 1 1.5

Sieve No.

Mix Design Preamble

With **economical cost** and **serviceability** in mind, concrete must obtain proper **workability**, **strength**, and **durability** requirements or the concrete mixture is considered worthless.

Designing Concrete

- **Techniques**
- Examples
  - W/cm
  - Agg gradation
  - SCM

- **Job req.**
- Examples
  - 3,000 psi
  - Slump range
  - F-T resist

- **Owner req.**
- Examples
  - cost<100K
  - +60 yrs

Laws of Mix Design

- **S**trength
- **W**orkability
- **E**conomical cost
- **D**urability
- **S**erviceability

Kind of Like Swedes, but only one "e"

Specifications

- Communicating requirements of job.
- Used to meet these “laws”.
- 4 types of specifications
- Common Concrete Specs
  - **Prescriptive:** specifies principles
  - **Performance**: specifies laws

Principles

- W/cm
- Admixtures
- SCM replacement
- Paste Volume
- Paste quality
- Air entrainment
- Setting time
- Aggregate gradation
- Aggregate: T, S, & A
- NM aggregate size
- H & C weather
- High strengths
- Heat of hydration
- Permeability

Laws of Mix Design

- **S**trength
- **W**orkability
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- **D**urability
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Law of Workability

- **Def:** Ability to mix, place, consolidate, and surface finish
- **Mix Parameters:** agg. gradation, paste vol., paste properties

Low Flow

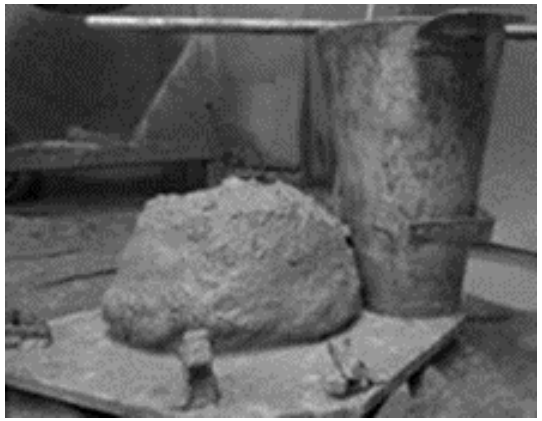
Segregation

Poor Finish

Communicating Workability

- Indicated by Slump Test

0 in. **5 in.** **10 in.**


Low Flow **Medium Flow** **High Flow**

Why Add Water on Site?!

Contractor Didn't Order Correctly

Producer has a Poor Workable Mixture

Note: Source of pictures are common internet memes

Effects of Agg. Proportioning

High Coarse

High Intermediate

(Same Paste Content & Properties)

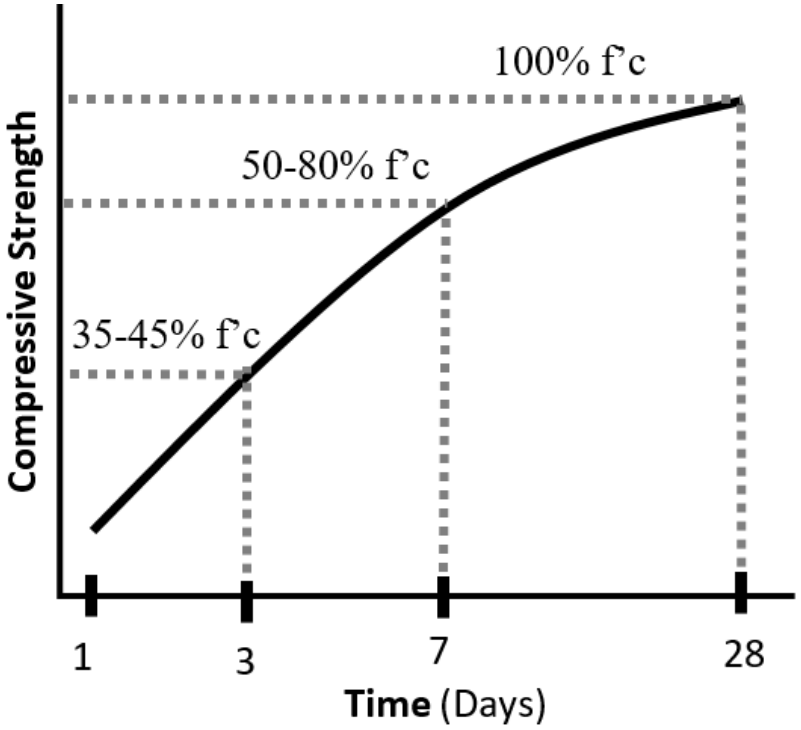
Moderate Amount

Deficient Sand

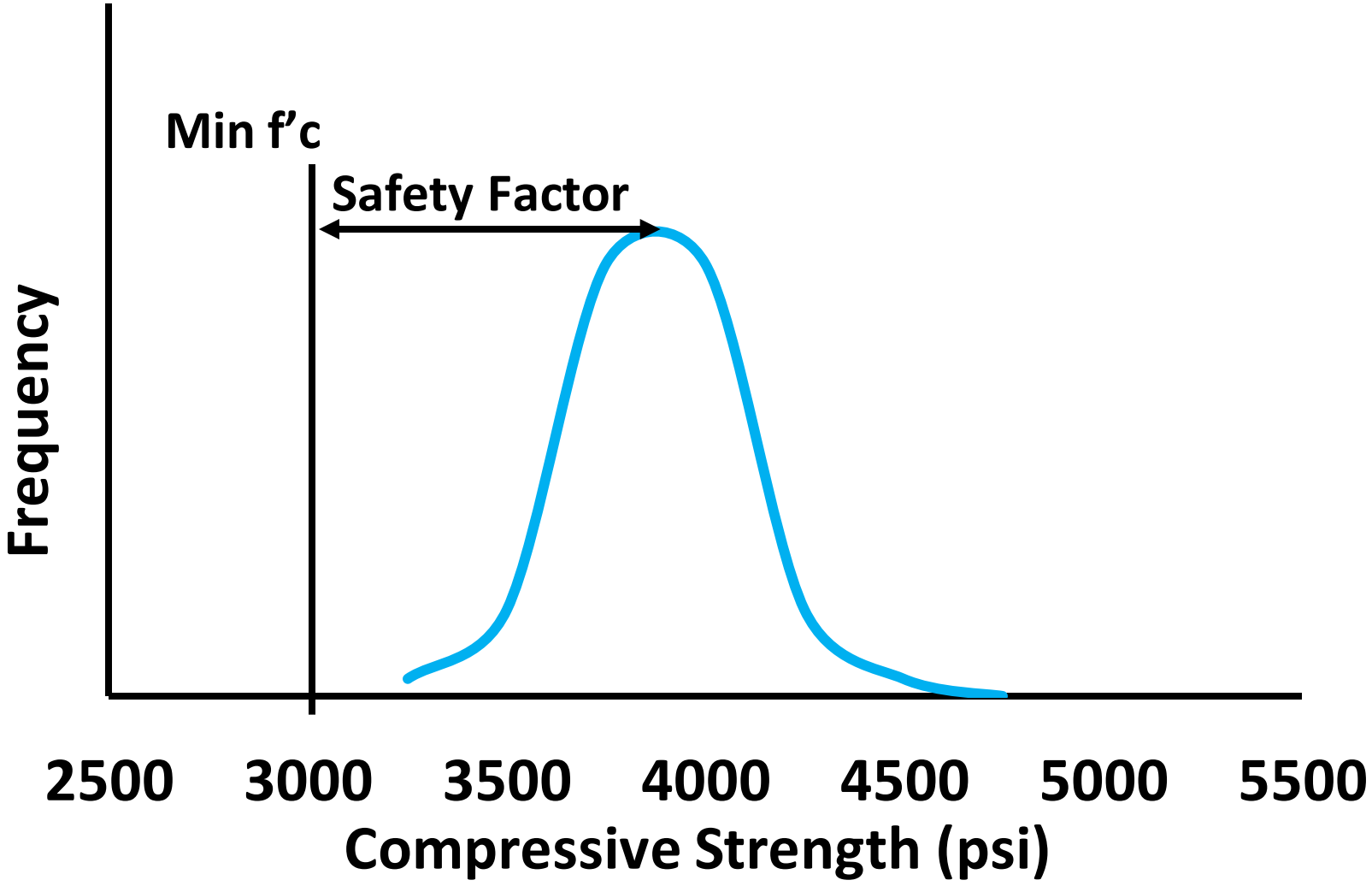
Excessive Sand

Law of Strength

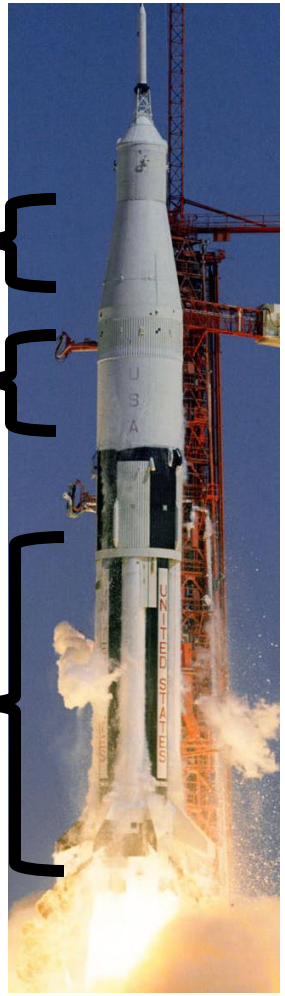
- Usually compressive strength (f'c)
- Normal Str.: 28 days
- HE Str.: 1 or 3-day
- High Str.: 28 or 56-day

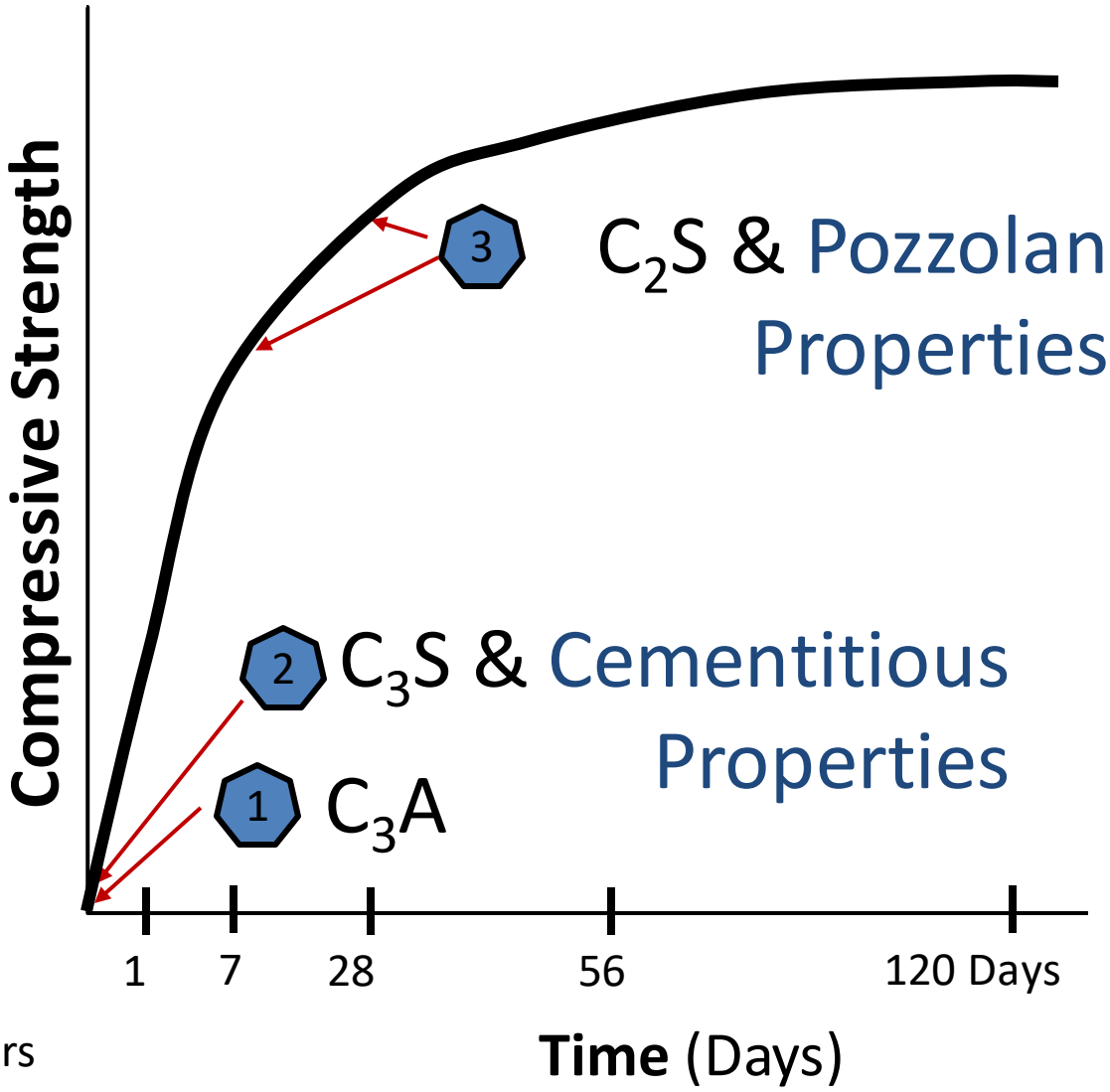


Design for Strength



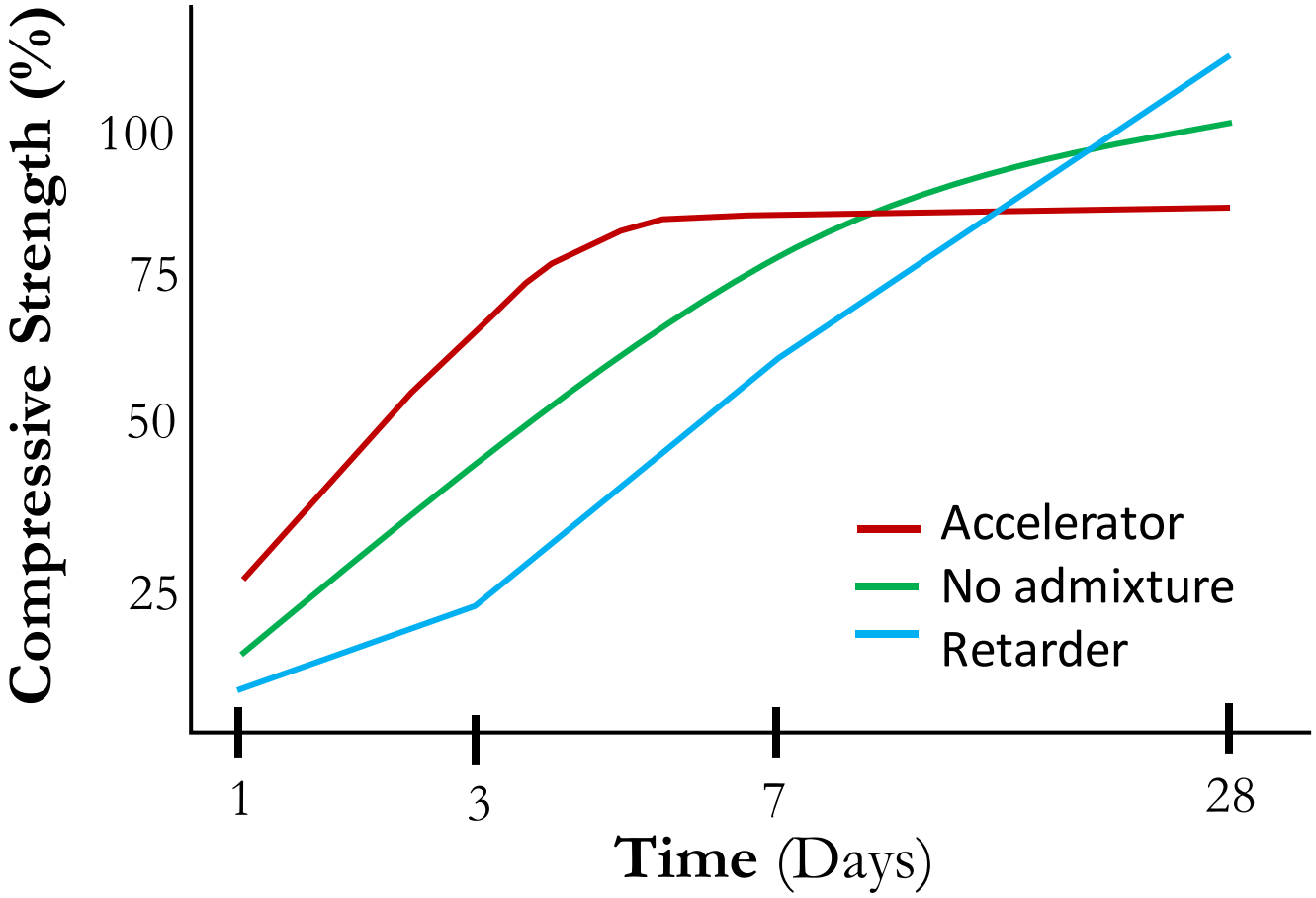
Cementitious Material





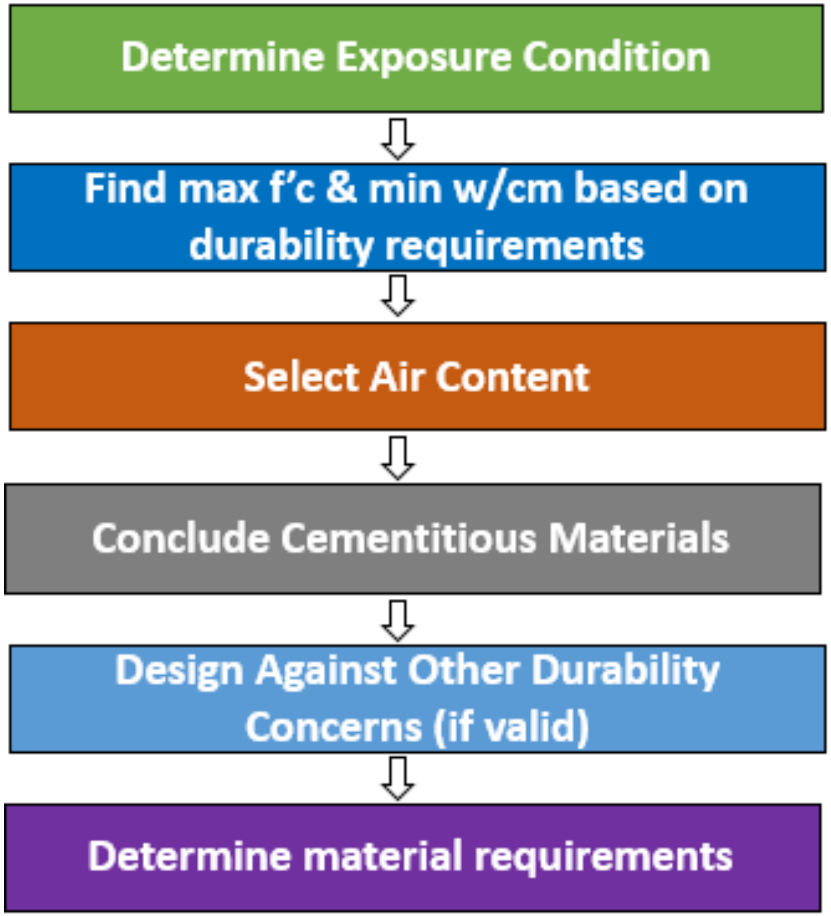
Speed depends on multiple factors

Principles of Admixtures



Law of Durability

- Based on exposure condition
- Select durable materials
- ACI 318 Mix design:
  - strength min
  - max w/cm
  - air content
  - cementitious material

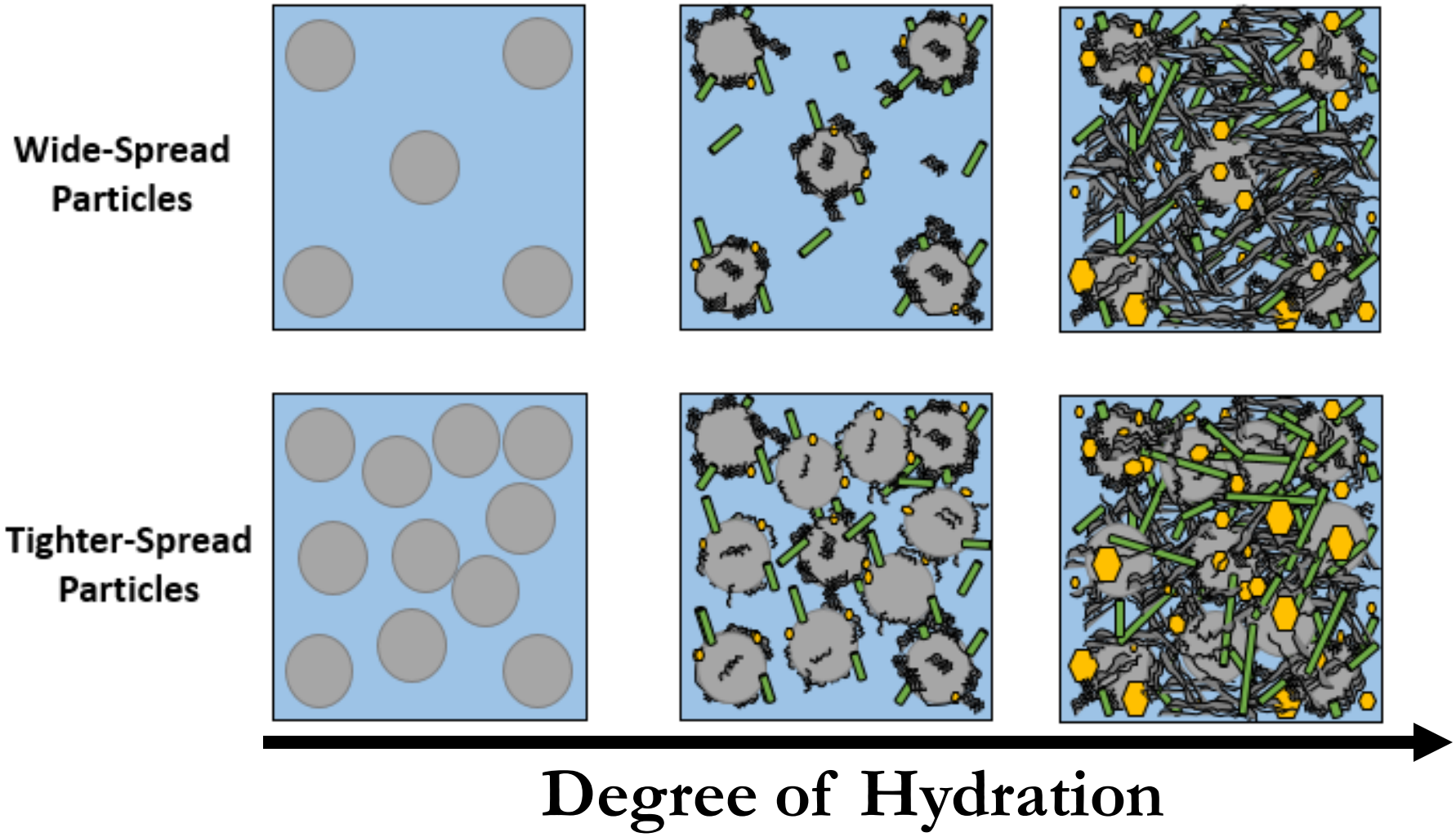


Principle of W/CM

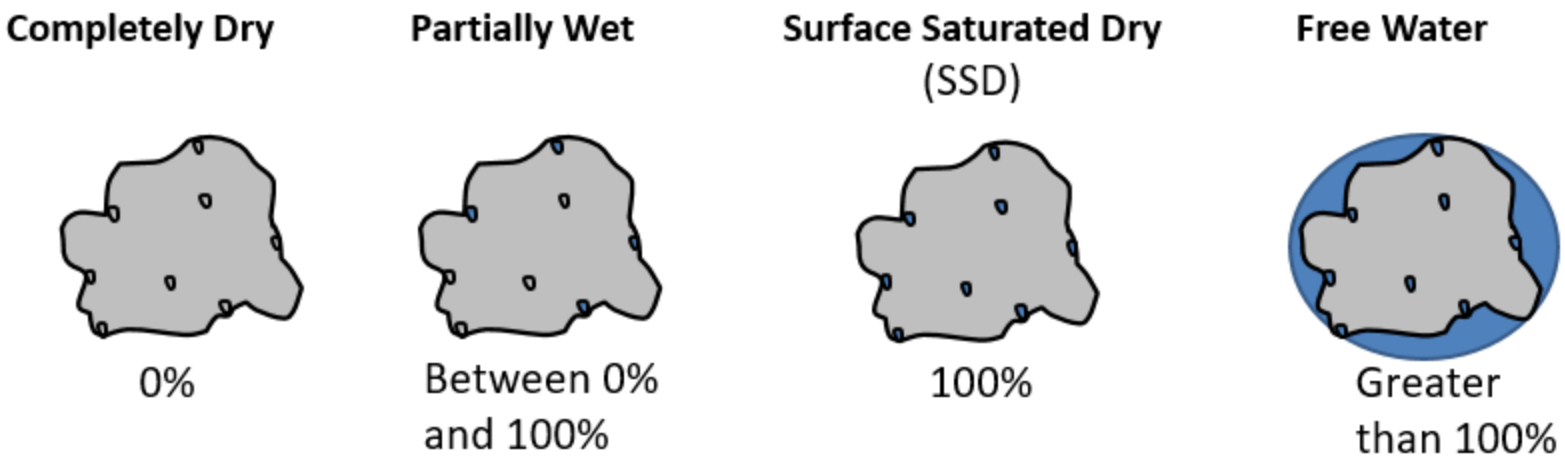
- Water-to-cementitious material (w/cm)
- Cementitious material: cement, fly ash, slag, silica fume, and/or other scm
- Sometimes called "Abrams Law"

$$\text{W/CM} = \frac{\text{Water}}{\text{Cementitious material}}$$

Concept of W/CM



Confusion with Water



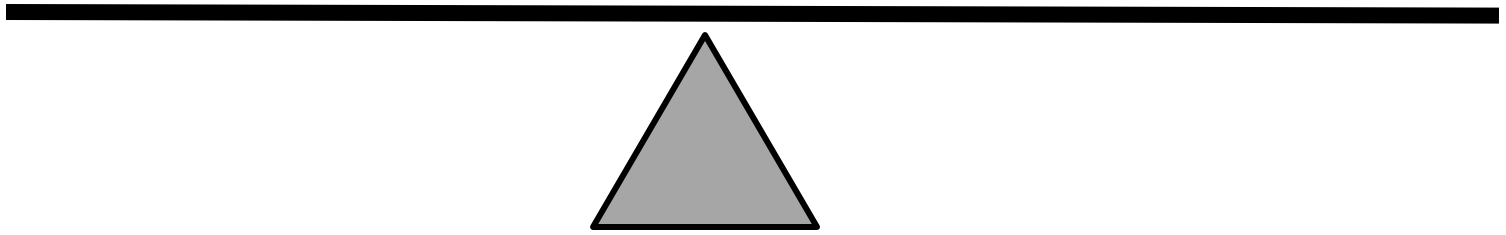
- Aggregate absorbs water.
- Design for SSD.
- Adjustments in aggregate moistures
- Water terms: design, free, batch, and trim

Law of Economical Cost

- Goal: produce cheapest mix possible
- Balance between cost & mix design

Mixture Design

Requirements



Design for Economical Cost

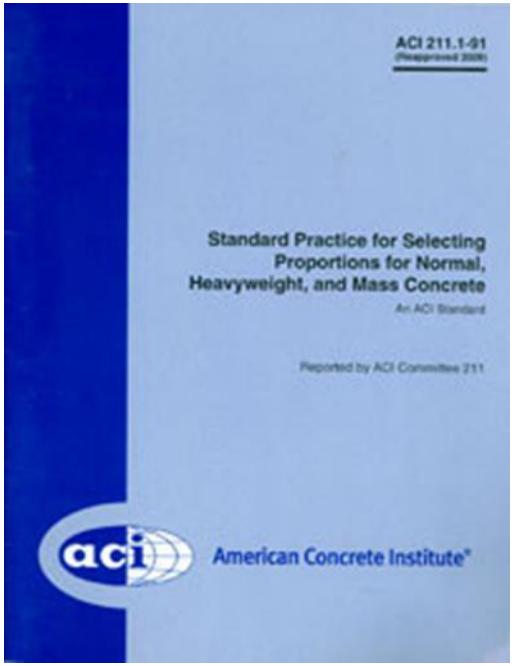
Material	Mixture 1		Mixture 2	
	Lbs./y^3	Cost	Lbs./y^3	Cost
Stone	1800	$16.20	1700	$15.30
Sand	1200	$12.00	1100	$11.00
Cement	564	$42.30	451	$33.83
Fly ash	0	---	113	$4.52
Admixture	---	---	---	$0.30
Water	252	$0.03	252	$0.03
Total		$70.53		$64.98

Law of Serviceability

- Meets user/owners needs.
- Example: smoothness
- Service life of a structure
  - Pavements: 30 to 50 yrs.
  - Bridge decks: 30 yrs.
  - Building: 99+ yrs.
  - Dam: 100+ yrs.

ACI 211 Method

- ACI 211.1-91 (Reapproved 2009)
- Absolute Volume Method
- PCA Design & Controls Book
- Provides first approximation
- Designs intended to be checked



Steps of ACI 211 Method

- Step 1: Choice of Slump
- Step 2: Maximum Size of Aggregate
- Step 3: Water and Air content
- Step 4: Water/Cement Ratio
- Step 5: Cement Content
- Step 6: Coarse Aggregate Content
- Step 7: Fine Aggregate Content
- Step 8: Adjustment for aggregate moisture
- Step 9: Trial Batch Adjustment

Design of 3,000 to 6,000 psi

Comp. Strength (psi)	w/c	Cement		Water		Aggregate	
		Sacks	lbs.	Gal	lbs.	Coarse (lbs./yd^3)	Fine (lbs./yd^3)
3,000	0.65	5.0	470	36.5	304	1800	1360
3,500	0.60	5.5	517	37.0	309	1800	1305
4,000	0.56	6.0	564	37.5	313	1800	1260
4,500	0.52	6.5	611	38.0	317	1800	1210
5,000	0.49	7.0	658	38.5	321	1800	1160
5,500	0.46	7.5	705	39.0	325	1800	1110
6,000	0.44	8.0	752	39.5	329	1800	1060

Note: Design is per cubic yard

Trial Batch & Testing

It may look good on paper but…

For More Information,

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